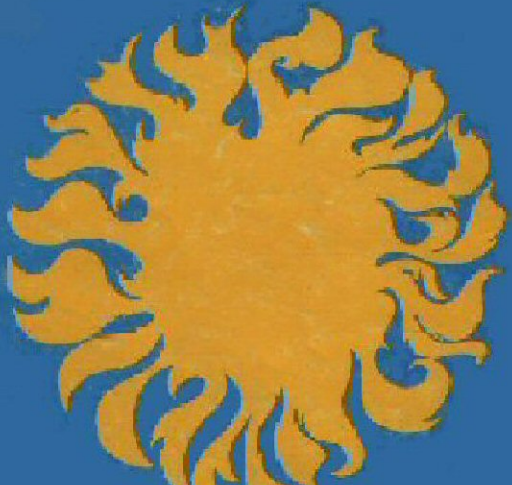
ISRAEL ENERGY NEWS



SPECIAL ISSUE COMMEMORATING THE INAUGURATION OF THE BEN-GURION SDE BOKER TEST CENTER FOR SOLAR ELECTRICITY GENERATING TECHNOLOGIES
FEBRUARY 25, 1987

Winter 1986

The Sde Boker Rationale

Laying the cornerstone of the Sde Boker center on Nov. 19, 1985, in the presence of then-Prime Minister Shimon Peres and Minister of Energy Moshe Shachal.

In November 1985, the Energy Ministry broke ground for the Ben-Gurion Sde Boker Test Center in the Negev desert, marking David Ben-Gurion's 99th birthday. In February 1987, the test center will be inaugurated. The ministry established this $1-million center to advance promising alternative energy technologies, particularly those involving electric power generation. It invited capable and interested Israeli and foreign entrepreneurs to install representative systems for performance verification over a limited but adequate time. All relevant technologies were acceptable for participation, provided they were ready for scaling-up and would probably be economically competitive with conventional systems within the next decade.

About 50 acres are available for the five-acre center's long-term expansion. It is expected to last many years, as advanced components and/or new technologies replace hardware relatively frequently. Participants own the installations while the ministry, which constructed and owns the center, runs, maintains, and—most important—monitors the representative facilities' performance and provides site services.

The Energy Ministry has long recognized alternative energy sources' potential for replacing imported fossil fuels, on which Israel heavily relies. Depending on technological development and anticipated economic aspects, solar electricity generation is projected to reach 200-500 megawatts installed by 2000. By concentrating on carefully selected projects and by mobilizing high-level scientific and technological manpower, sometimes coupled with sophisticated adaptations and modifications of foreign know-how, Israel has shown impressive results. Solar water heaters, water desalination, solar ponds, and advanced parabolic trough solar collectors are examples.

In selecting solar energy generating technologies suitable for large-scale commercialization, the ministry considered solar technology's site specificity and recognized that employing others' experience and know-how could be misleading and damaging. Furthermore, it acknowledged that available foreign data often conflict and lack a common reference, objectivity, and reliability. Finally, it realized that some locally developed technologies were unproven and required a common yardstick for comparison. Therefore, the ministry established the test center.

The ministry funded construction, operating, and maintenance and provided incentives by sharing entrepreneurs' expenses. This sharing permits cost-effectiveness for all parties, as well as sharing the valuable certified performance data to be produced at the test site. Considering the anticipated value of the data to be obtained, the national resources allocated to the center were much lower than for comparable programs abroad, as representative technologies' power ratings were carefully selected and expenditure sharing was cautiously calculated. Once the center is running routinely, it should host new and improved technologies for years.

Objectives

The test center will assess available foreign and local solar electricity generating technologies' prospects of achieving commercial competitiveness during the next decade, to be proven under field conditions. It will gain comparative reliable performance characteristics and project the economics of qualified technologies operating side-by-side under the same conditions. Furthermore, it will encourage entrepreneurs to commercialize their developing technologies and lessen the time and resources required to decide to commercialize or discontinue efforts. Experience accumulated at the site and elsewhere will provide valuable lessons, with readily exchangeable systems and components. Additionally, neighboring facilities' owners can share know-how and collaborate; perhaps the most successful features can be merged into a better system. Local cooperation with Israeli and foreign scientists in developing commercial systems and components will be enhanced, as will technological and commercial cooperation with friendly developed countries. A stronger data base will be formed, especially utilizable in sun-belt developing nations, particularly those lacking electrical networks. Israel's balance of payments should also improve through entry into international energy markets.

Participation Criteria

Not every technology is suitable for test-site participation. The Energy Ministry accepts only technologies that are past applied research and that have proven technically mature and likely to compete economically with conventional systems within 10 years. If unrelated to a different power rating, each photovoltaic installation must output a net 5-kilowatt-hours of electricity and each solar thermal system, at least a net 25, based on reference peak insolation of one kilowatt per square meter.

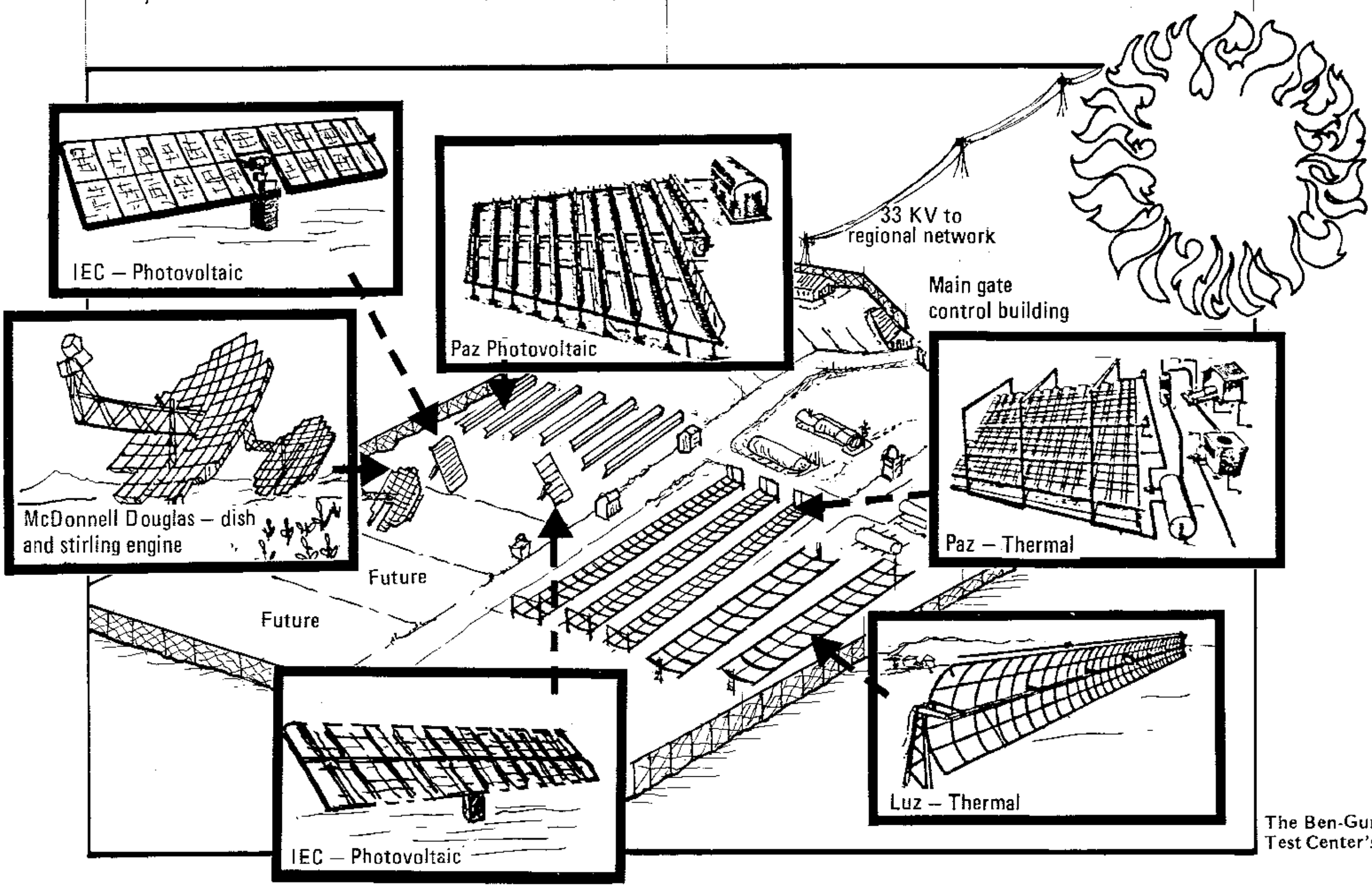
Each facility will be test-monitored for two years and then dismantled to make room for another, unless the ministry continues testing. The ministry will be fully compensated for the electricity generated and sold to the Israel Electric Corp. to cover part of operation costs.

It has constructed a complete infrastructure including site services, maintenance facilities, a fully equipped, computerized data-logging and -processing system, a meteorology station, and a qualified team to operate, maintain, and monitor all systems and facilities and tend to security. The ministry will document, certify, and publish each technology's performance parameters, under real field conditions.

Any foreign participant must collaborate with a local company capable of implementing the proposed system. It must also provide backup, guidance, O&M, training, and advanced maintenance to maximize results, as is true for local participants.

Major Site Features

The (first phase) center configuration contains a southern testing area and a smaller, northern site-services area. The first section's western part is



The Ben-Gurion Test Center's layout.

allocated for solar photovoltaic representative systems, while its eastern wing can accommodate solar thermal systems. Internal access tracks, water piping, electric cables, and data-transmitting and remote-control wires underground monitor each tested technology. The site-services area houses the control building, main water supply, and electrical connections with the regional water system and grid, respectively; an electrical main switchboard, water tank, and water-conditioning facility; a fuel tank (for fossil-steam backup and superheating); turbo-generators, cooling towers, and solar-thermal-system condensers; and firefighting apparatus, etc.

A security fence with a main, controlled gate on the northern leg surrounds the area. The fence is illuminated for security. An approach road from the Desert Research Institute, 500 meters away, serves overland communication. Electrical connection with the Israel Electric Corp.'s 33-kilovolt regional grid is by a two-way metering system and a 250-kilovolt-ampere transformer, connecting with the site-3-phase, 380-volt, 50-cycle electrical network.

The control building contains the main control room, with its computerized data-logging and -processing system, and its peripherals, an uninterrupted power supply, means to monitor and remotely control all representative facilities and major site operating systems, and a telephone communication system; an instrument room and laboratory; a small conference room; offices; and a kitchenette and sanitary services. The building will be conventionally air-conditioned, although a solar-energy-driven air conditioner might be integrated.

Data Logging and Processing

Each tested installation will be equipped with measuring instruments, most of them capable of transmitting data to the central computerized data-logging and -processing system, situated in the main control room. Among other representative values, the following performance indicators will be computer-processed from incoming and stored data, displayed, and, if desired, printed (charts, curves, bar graphs, tables, etc.) as selected by the appropriate command:

- Electricity outputs and energies delivered versus insolation and ambient conditions.
- Conversion efficiencies: solar radiation to thermal and/or electrical energy, auxiliary power consumption, parasitic losses, DC to AC and AC to grid, etc.
- Insolation and plant capacity factors.
- Operating reliability and system availability.
- System economics (reference annual cost to install and operate, amount of electricity generated, capital recovery factors, delivered electricity costs, etc.).

Project Management

Ministry officials, headed by the chief scientist, direct the project, one person acting as coordinator. A steering committee appointed by the ministry director-general meets regularly for progress briefings, evaluation, recommendations, and major decisions. All but two members are non-ministry personnel from scientific institutions and energy companies. Petroleum Services Ltd., a veteran oil company, is the main contractor for planning and constructing the center and its infrastructure and services, including the necessary interfacing with the representative technologies to be monitored for performance.

The Test Center Site and Installations

Construction of the soon-to-be-inaugurated Ben-Gurion Sde Boker Test Center for Solar Electricity Generating Technologies is in high gear and both central and individual companies' facilities are being installed. Gideon Carmel, Sde Boker Test Center project coordinator and Energy Ministry consultant, describes the preparations:

Central Installations and Infrastructure

When various entrepreneurs were invited last year to participate in the Sde Boker site, the Energy Ministry promised, aside from a 30% subsidy of initial costs, a well-developed infrastructure and data-acquisition-processing system. Investment in the site has exceeded $1 million and was carefully planned to maximize information produced at Sde Boker. While each company is responsible for its project installation and local data handling, the ministry has provided roads and ductwork for communications and electricity, central services such as water, and total site operation and maintenance through the Petroleum Services Ltd.; obviously, the ministry's investment surpasses the nominal 30% grant for each project.

But it looks like this money will be well-spent. Aside from relieving each participant of maintenance and infrastructure headaches, the site boasts a data-acquisition and -processing system designed by Dr. Moshe Hirsch. For each exhibitor on the five-acre site a two-level data system is installed alongside his photovoltaic, thermal, or other energy-generation plant. The first level includes measuring elements like sensors and transducers to determine global and direct radiation, collectors' angular position, and supply constant on-line records of current, voltage and electricity output, plant temperature, and thermal collectors' reflectivity, flow, pressure, and auxiliary power demand. These data will be entered into the installation's microcomputer, located at the main control room.

The second level is the central multitasking data processor, which communicates with the microcomputers to collect comparative data, organize field results, and undertake basic statistical processing and graphing.

Novel and extremely sophisticated, the central data system serves as an objective performance-measurement tool and is not only useful to the Ministry's evaluation of how each demonstration project works, but also benefits each company at the site. The detailed monthly report on events, operation, output, and efficiency is officially documented and can provide a strong marketing point. (Every entrepreneur has a 45-day reply period, however, before any report is released publicly.)

Sufficient flexibility has been built into the system to permit future additional parameters, especially significant in view of the potential for communicating through modems with Israeli and other centers as data begin to flow.

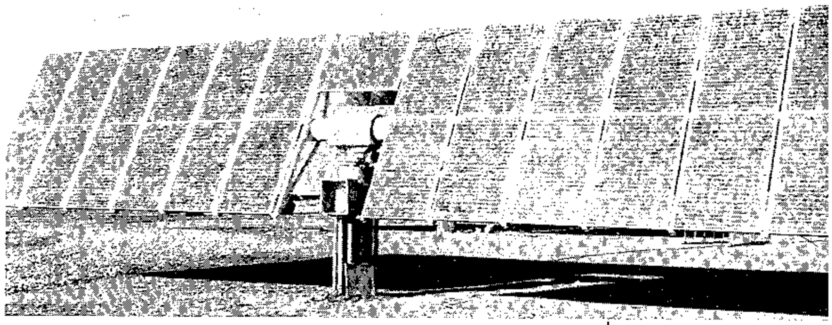
Electricity output from the project will be three-phase, 380-volt/50-cycle and stepped up to enter the regional 33-kilovolt grid; from the start, the test site will not only be a demonstration facility, it will supply electricity to the Negev.

IEC The Israel Electric Corp. Installation

The Israel Electric Corp. (IEC) has been researching photovoltaic electricity generation since 1982; when it decided to construct a demonstration facility in 1985, the Energy Ministry fortuitously approached them and proposed entering the Sde Boker project. David Fisher, photovoltaic-project head at the IEC research and development division in Haifa, recalls the company's plunge into a new field:

Selecting a Demonstration Project

Though the photovoltaic effect (electricity generation directly from the sun) has been known for over a century, only recently has it been applied commercially (see *Israel Energy News*, Spring 1986). It is the cleanest and most universally available renewable energy: direct and diffuse sunlight reaches the earth at levels of 1,000 or more watts per square meter. The most practical way to transform sunlight directly into electricity is through a semiconducting material like silicon. Readily obtainable, silicon is grown in



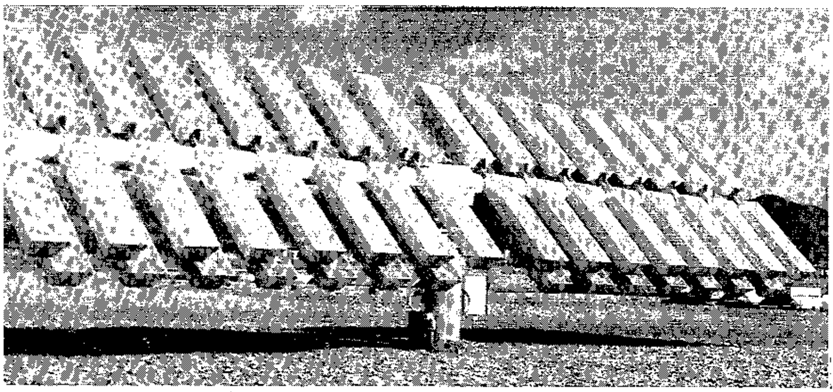
Polycrystal photovoltaic collecting panels.

pure crystals and doped with boron and phosphorus to allow electrons to flow freely within the silicon upon exposure to light. Accumulator strips at the silicon's edges lead the flowing current to the consumer, either from a single cell or from a group.

Photovoltaic power's advantages are plentiful: installation is fast, maintenance is minimal, little water is required for occasional collector cleaning, it is non-polluting, and is suitable for isolated locales and peak electricity supply. Some problems do exist: the relatively high price deters widespread use, backup electricity is required for non-daylight hours, relative inefficiency and large surface areas have prevented many applications, and long-term photovoltaic-cell stability and availability are unclear. Nevertheless, mainly based on a near-future expected breakthrough, the IEC ordered photovoltaic cells from several suppliers and ran comparative tests in both laboratory and outdoor conditions, including continuous real-time behavior records. Surveys of the Israeli potential revealed that rooftop household photovoltaic generators could produce as much as 228 megawatts of electricity.

The IEC thus decided to incorporate several recent photovoltaic innovations in the Sde Boker project to enhance the IEC photovoltaic system's efficiency: sun tracking and concentrated lenses. But it first decided which cell type to use. Essentially three main photovoltaic-cell types are available: single crystal, polycrystal, and amorphous. The single-crystal type is made of waffles cut from a carefully grown, pure silicon crystal and is relatively expensive to produce. Polycrystal cells are made of a mosaic of smaller silicon crystals. They cost less but are somewhat less efficient due to the borders between crystals. Finally, the more advanced amorphous cells are made of a thin silicon layer evaporated onto a glass or polymer support. The IEC is installing two systems, with amorphous cells in one and a concentrated lens in the other, using small single-crystal cells.

The first system to be installed consists of panels made up of many amorphous photovoltaic cells mounted on a long supporting pole. A computerized control system allows full sun tracking along a double axis. The second system, which will be erected several months later and is also fully tracking, is based on small, single-crystal cells (about 1-2.5 square centimeters) with a Fresnel lens mounted above each to concentrate solar radiation. In the laboratory, such lenses increase radiation intensity on the cell 10-fold to 100-fold and efficiencies have reached as much as 23%; overall efficiency of the lens/cell system is 16%, which is about 4% higher than that of most photovoltaic cells. The IEC is attempting to test such impressive results in a field demonstration at Sde Boker.



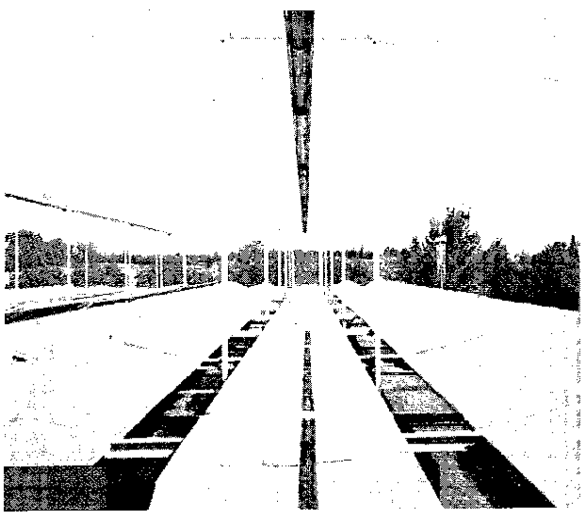
Amorphous photovoltaic collectors with concentrating lenses.

Potential Output

The IEC cells should produce the reasonable output the Energy Ministry requires of demonstration projects designed to provide useful data for large-scale planning. At the first stage, 3.5-4.5 kilowatts will be produced, and after several months' running-in, a five- to six-kilowatt concentrating array will be implemented during the project's second phase, feeding into the site grid.

The Paz Oil Co. Installation

Paz Oil Co. Ltd. is a major Israeli energy firm best-known for dealing with conventional energy sources. However, it has been moving into alternative energy with projects like Sde Boker. Dr. Eytan Yanir, Paz's



Investment in the site has exceeded $1 million...

research and development manager, discusses his company's installation at the Negev center:

Two Roads to Solar Energy

Paz was the first company to join the Energy Ministry at Sde Boker and worked hand-in-hand with ministry planners during the initial stages of selecting contractors for site work, equipment and instrumentation, etc. Its Sde Boker photovoltaics project is under construction and it is planning a thermal-energy installation.

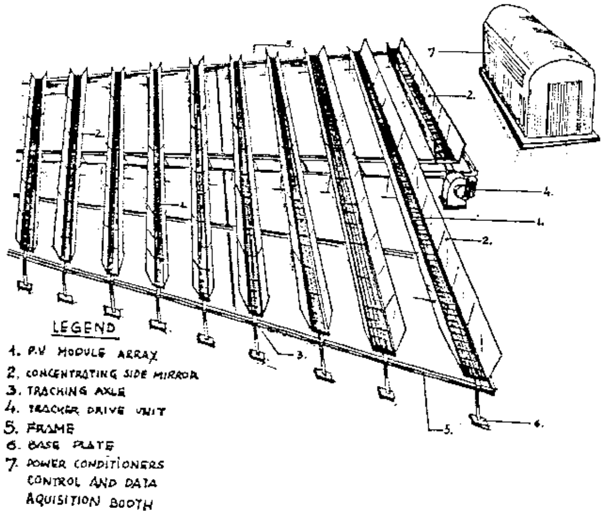
The Paz team's major problem was reducing photovoltaic-installation prices to permit efficient power stations. Solar-radiation concentrators were costly and complicated so a simpler solution was found: a photovoltaic panel with two plane mirrors angled on both sides and single-axis (east-west) sun tracking. The tracking system increases installation costs by about 12% – to a still unexpectedly low $180,000 – but doubles yearly output. The complete Sde Boker unit produces DC (direct current) electricity that is converted to AC for grid supply. The anticipated peak output is 10 kilowatts.

Paz inspected many photovoltaic-cell suppliers before choosing Solarex, an American firm. One single-crystal cell type, based on a polycrystalline silicon wafer, will initially minimalize variables; later, different cell types will be checked. Polycrystalline cells will be used because they're more reliable than amorphous cells in the long run.

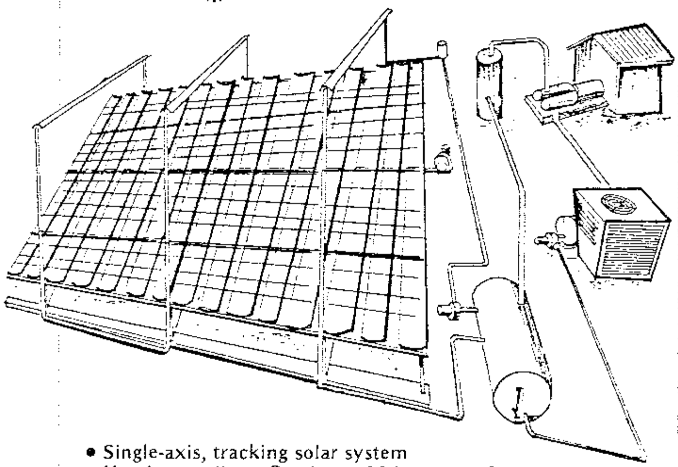
Thermal Electricity-Generation Systems

Paz and Pimat have developed a thermal system that creates 200°C steam from the sun, using a tracking system to follow the sunlight. Steam generated is usable directly for industrial purposes like food processing or it can be fed into turbines for electricity generation. The system, dubbed CS-112, is commercialized and costs one-third as much as most thermal networks – $150 per square meter installed. The simple structure consists of concave mirrors that follow the sun and concentrate its radiation onto a central receiver. It can generate electricity via either a Rankine-cycle turbine using the 200°C steam or hot-oil energy converted to hydrocarbon fluid , or small fuel-oil amounts can superheat steam to 400°C, which is quite efficient for electricity production.

The Sde Boker system will consist of 750 square meters of mirrors and a 30-kilowatt steam engine or



Paz Oil Co. 10 Kilowatt Peak Photovoltaic Power Unit



Paz Oil Co. Solar Thermal Power Plant

- Single-axis, tracking solar system
- Heating medium: Paztherm 22 heat-transfer oil
- Net solar-reflector area: 750 square meters
- Concentration ratio: 20:1
- Solar conversion efficiency: 45%
- Fossil-fuel backup (including superheating): up to 25% of total energy required for conversion to electricity
- Power block efficiency: 10%
- Solar contribution: 200 kilowatts net at one-kilowatt-per-square-meter global insolation, with 77% direct radiation
- Electric output: 30 kilowatts net peak

turbogenerator. Initially, Paz would like to construct the steam generator and later install one or more of the following innovative components: a waste or biomass-fueled backup and/or superheater unit; a dry and/or dry-wet cooling tower; absorption cooling or refrigeration; an organic Rankine-cycle turbogenerator.

The Paz R&D team is convinced that there is an unexploited market, such as hospitals and hotels, requiring steam generation where current systems are inefficient. These systems must be located far from the end-user, due to pollution caused by fossil fuels, and substantial energy is lost during steam transmission. The proposed, stand-alone Paz system is as clean as the sun and can be placed very near users in the textile, food, metal-finishing, and pharmaceutical industries; it's also applicable to absorption cooling and refrigeration.

Why is an oil company entering the alternative-energy field? Not only does it offer a competitive edge on one-track oil companies, it makes both business and technological sense. Many large energy concerns produce energy systems and Paz is following that trend. In planning the Sde Boker installation, it gained valuable experience from selecting and working with the control-system and electric-hardware company. Paz foresees solar energy moving away from small producers useful on the household level and towards larger companies technically and financially able to handle commercial projects. The Sde Boker Test Center will effectively give a performance certificate to its participants in acquiring extensive data.

The Luz Installation

Jerusalem- and Los Angeles-based Luz International's several hundred employees design, market, and manage solar-energy projects. A major Southern California installation produces over 100 megawatts. Their much smaller-scale Sde Boker project will introduce their unique and successful product to Israel. Luz Industries Israel's Yahal Zilka describes it:

Luz's basic unit for producing electricity from the sun is an SCA, or solar collector assembly. The Sde Boker version will be of the Luz System-2 type, in which 235 square meters of parabolic mirrors concentrate solar radiation on a central pipe assembly.

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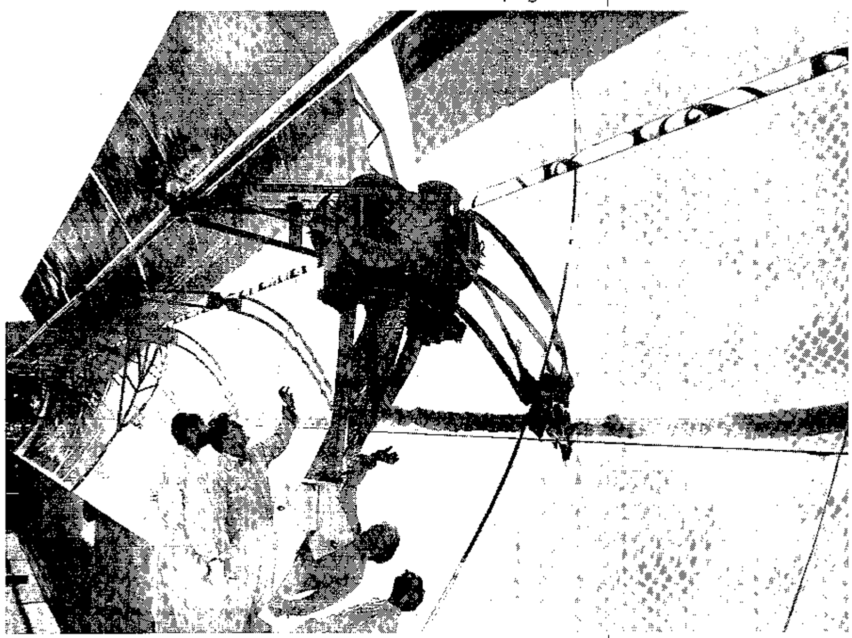
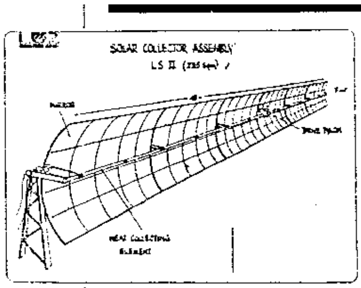


A typical Luz LS-2 solar mirror unit.

For a look at the Sde Boker data system, turn to page 19.



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The Test Center Site and Installations

With an aperture five meters in diameter, the 48-meter-long SCA focuses on the heat-collecting element (HCE), which is centrally located within the parabola. The HCE is a pipe composed of an inner, stainless-steel tube containing oil or a heat-transfer fluid and an outer, glass envelope, with a vacuum of 10^{-4} Torr between the inner and outer tubes to maximize thermal insulation. The SCA tracks the sun with extraordinary precision, using an electronic tracking system based on a central sun sensor and a local control-unit computer. The Sde Boker site will contain four such SCAs, totaling 940 square meters of collecting surface. First, the unit will use a steam generator, a condenser, and a cooling tower to produce saturated steam for industrial use. Later, a superheater, turbine, and generator will be installed to produce electricity.

The electricity-generation potential is in the kilowatts, which is far lower than Luz's typical operating conditions. However, the company hopes to erect SCAs to provide 25 megawatts of electricity to the IEC. It is examining eight alternative Negev sites, cooperating with the Energy Ministry. Luz sees constructing an Israeli installation as a challenge. Not only would using free, indigenous sunlight for electricity reduce dependence on fossil fuels for electricity, but siting in the Negev could spur regional and technological development.